Chapter 2

STARTING SYSTEMS FOR GAS TURBINE AIRCRAFT ENGINES

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INTRODUCTION

General

1. This chapter covers the electrical aspects of the general principles of gas turbine starting systems for aircraft, and describes circuits typical of the various systems in use. The starting system installed in a particular aircraft may, however, be somewhat modified in accordance with design features peculiar to that aircraft, its engine, or its electrical system. The relevant Aircraft Handbook should therefore be consulted for full details of a particular starting system.

2. The components of the various starting systems may also differ in detail. Full descriptions of all these components are outside the scope of this chapter, but may be found in other publications of the A.P.4343 series.

Note . . .
Detailed information on the mechanical aspects and operational sequence of the system are given in A.P.1181B, Vol. 1 and Vol. 6.

Engine starting

3. The process of starting a gas turbine engine involves the simultaneous igniting of the fuel and the running up of the engine rotor to a speed at which the flow of air is sufficient to maintain combustion, the engine developing sufficient power at this speed to drive its compressor and so become self-sustaining.

4. There are two types of prime mover in use for running the engine rotor up to speed. The one type is an electrical motor, and the other is a small high speed auxiliary turbine driven by high pressure gases generated by the burning of a cartridge or the combustion of a suitable fuel. In both types, the drive is transmitted from the prime mover to the engine rotor through a clutch and reduction gearing.

5. The function of a starting system is to perform the operations necessary for starting the engine in a definite time sequence, and then to re-set automatically in readiness for a further cycle. Certain safety features must be integral with the system to avoid overloading, to prevent the firing of more than one cartridge at a time, or to protect turbo-starters from damage due to over speeding under unexpectedly reduced loading.

STARTING SYSTEMS

General characteristics

6. In all systems, the supply for the starting system itself is taken from the 28-volt battery installed in the aircraft, through a fuse to a master starting switch. The closing of this switch starts up the fuel pumps. The starting sequence is initiated by the depression of the starter push switch, which, once depressed, holds in until the starting cycle is complete. Before starting, it is necessary for the throttle lever to be moved back against the slow running stop. To ensure that this has been done, a safety feature in the form of a throttle micro-switch is incorporated in the starting system, the circuit remaining open until the throttle is in the correct position.

7. Motor operated starters require a heavier current than can be supplied by the aircraft batteries, and hence the current for the motor is obtained externally from a ground supply via a starter socket in the aircraft. Where an aircraft is equipped with a 112-volt system, an emergency start may be made from the aircraft batteries, but under normal conditions the ground supply is used. This heavy current supply is not necessary where liquid fuel or cartridge-operated turbo-starters are installed.

8. On depression of the starter push switch, a time delay switch is energized. This switch controls the sequence of operations necessary for starting the engine. It closes circuits which operate the torch igniter fuel valve and the spill or bleed-off valve. It also energizes the high energy ignition units which supply the power necessary for the sparking plugs of the torch igniters. In the case of the motor operated starter the time delay switch also controls the current fed to the motor, while in the case of the cartridge-operated turbo-starter it completes the cartridge firing circuit.

9. The duration of the time delay switch cycle allows ample time for an engine start. On completion of the cycle, all operating circuits are opened, the starter push switch is released, and the system is re-set for a further start.

10. Another feature common to most starting systems is a relight push switch used for restarting an engine in flight. Since the engine is windmilling under flight conditions, no power is required to speed up the engine rotor, and the normal ground starting sequence is therefore unnecessary. On depressing the relight push switch, a supply by-passes the time delay switch and energizes the high energy ignition units directly. The torch igniter fuel valve is also operated.

Motor starters

11. The circuit in fig. 1 shows the main details of an older type of starting system used on single-engined aircraft such as the Vampire. To start the engine, the ground supply is plugged into the starter socket, the throttle lever is moved back against the slow running stop (closing the throttle micro-switch), and the master switch is closed, thus starting up the fuel pumps. On depressing the starter push switch, the following sequence of operations takes place:—

(1) The coil of the time delay switch is energized via the normally closed contacts T1. This winds up the switch mechanism. At the same time the shunt coil of the slow engagement relay is energized and closes the relay contacts, thus completing the ground supply circuit through the current limiting resistors R1 and R2 to the starter motor. The motor then commences to run, engaging the clutch and starting the engine rotor turning. The high energy ignition units are also energized.

(2) When the starter push switch is released, the supply to the time delay switch coil and to the slow engagement relay shunt coil is cut off. The latter relay remains closed, however, held in by its series coil S. Upon de-energizing the time delay switch coil, its mechanism commences to unwind. After about three seconds, the normally open contacts T2 close and energize relay 1. The contacts of this relay close and so short out resistor R1 and the slow engagement relay, which now reopens. The starter motor current rises to around 800 amp. and the motor speeds up.

(3) After a further time interval, contacts T3 on the time delay switch close and energize relay 2. When the contacts of this relay close, relay 1 and

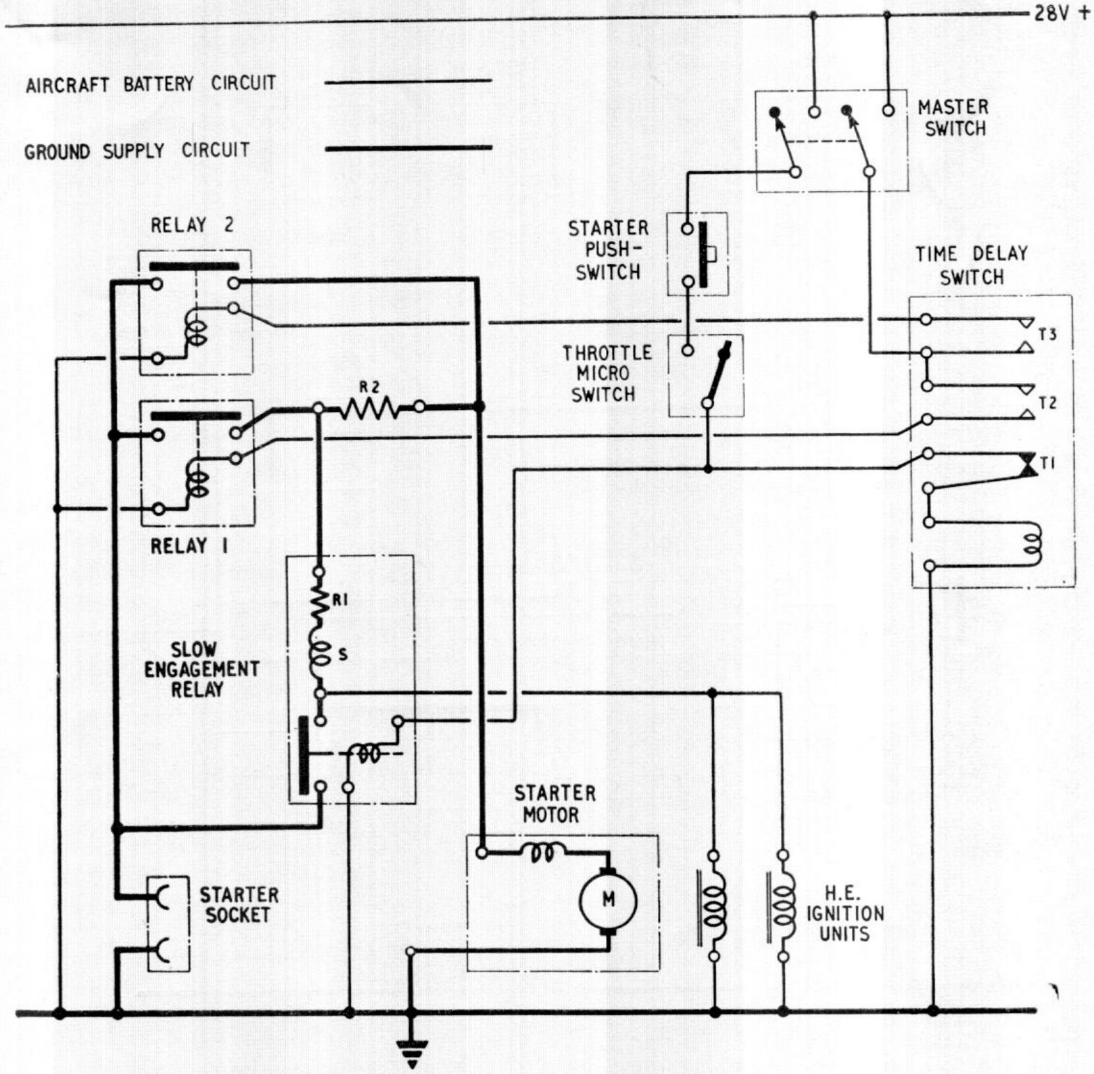

Fig. 1. Motor starting system

current limiting resistor R2 are shorted out. The current now rises to about 1,000 amp., and the engine rotor is run up to its starting speed.

(4) The time delay switch completes its unwinding cycle in about 30 seconds and re-opens contacts T2 and T3. This de-energizes relays 1 and 2, thus cutting off the supplies to the starter motor and high energy ignition units. Finally, contacts T1 re-close in readiness for a further start.

12. A system similar to that shown in fig. 1 is used to start each engine of Meteor aircraft. The slow engagement relay is, however, dispensed with, the starter motor running up from standstill when relay 1 operates. The high energy ignition units are not energized until the time delay switch contacts T3 close and operate an additional relay (not shown in fig. 1).

13. The circuit of fig. 2 shows a starting system applicable to a four-engined aircraft. A common starter push switch and time delay switch circuit serves each engine in turn by

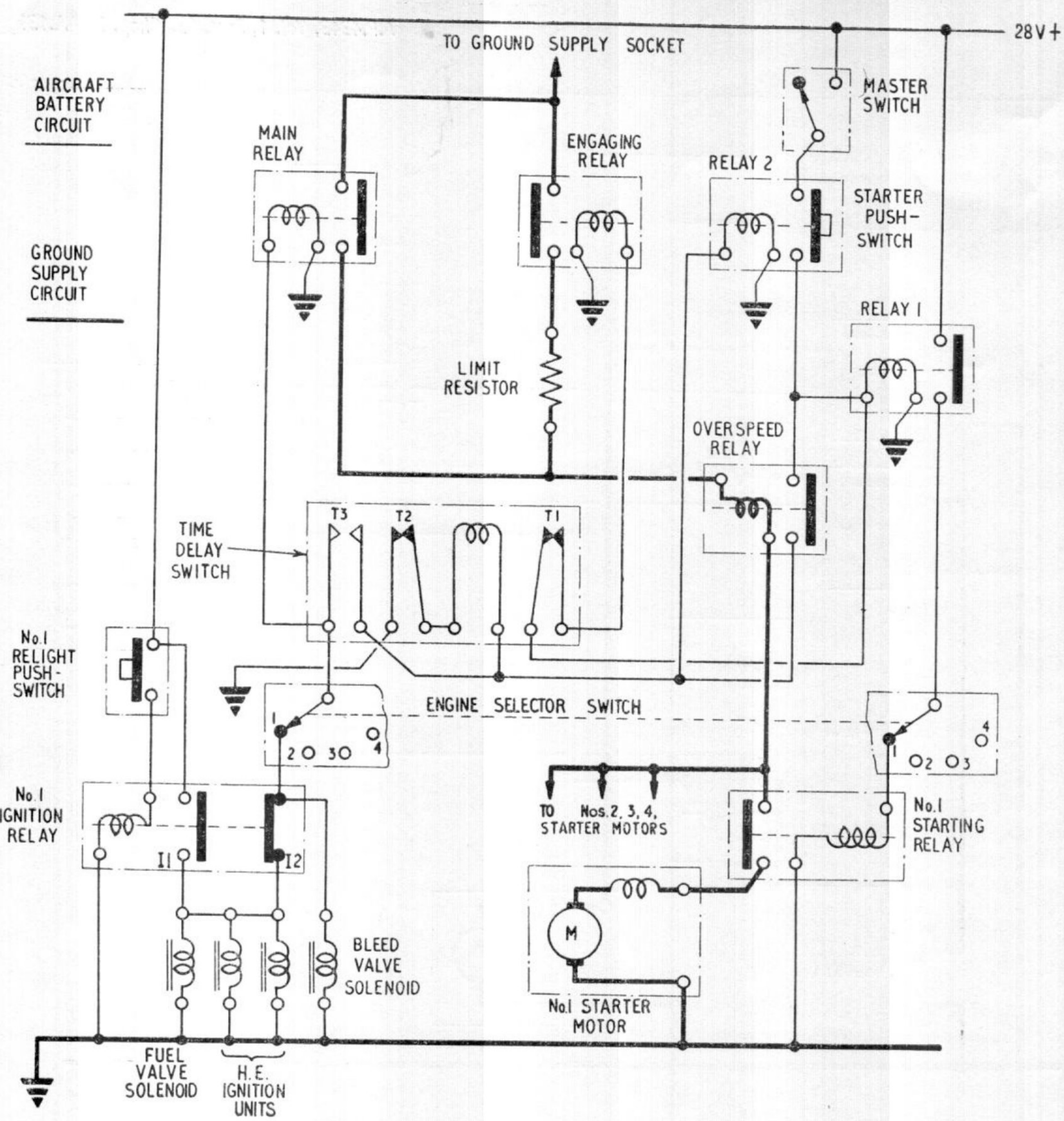

Fig. 2. System for four-engined aircraft

means of a double-pole, four-way, engine selector switch. Each engine is provided with its own starter motor, starting and ignition relays, ignition units, relight push switch, and fuel and bleed-off valves. To start an engine, the ground supply is plugged into its socket, the master switch closed, and the engine selector switch moved to the required engine position. The sequence of operations is as follows:—

(1) Operation of the starter push switch energises the engaging relay through the normally closed contacts T1 of the time delay switch. At the same time, the selected starting relay is energized by the operation of relay 1.

(2) The contacts of the engaging relay close and connect the heavy current ground supply to the starter motor, through the current limit resistor and the overspeed relay. As the current through the overspeed relay rises, its contacts close and energize the coil of relay 2, which then holds in the starter push switch. The closing of the overspeed relay contacts also energizes the coil of the time delay switch which winds up the switch mechanism.

(3) On completion of winding, the time delay switch contacts T2 open and interrupt the coil circuit. The time delay mechanism then commences unwinding, and after sufficient time has elapsed for the starter motor to get under way, it causes the normally open contacts T3 to close. This energizes the main relay, the contacts of which close and short out the limit resistor, thus permitting the full current to flow through the starter motor; so enabling it to run up to the engine starting speed.

(4) The time delay switch contacts T3 also supply current via the engine selector switch to the bleed-off valve solenoid. The fuel valve solenoid and the high energy ignition units are also supplied through the normally closed contacts 12 of the ignition relay.

(5) The engine now starts and maintains its speed. There is a consequent drop in the starter motor current, which causes the overspeed relay to re-open its contacts. As a result, the supplies to the bleed-off and fuel valve solenoids, the high energy ignition units and the main relay are cut off. Relay 2 is also de-energized and releases the starter push switch. Relay 1, and hence the starting and engagement relays are de-energized. The starter motor circuit is thus opened. At the conclusion of the time delay switch cycle, contacts T3 open, and contacts T2 close in readiness for a further start.

(6) Should the engine fail to start, the starter motor current will remain at its full driving value, and the overspeed relay will not re-open. The time delay switch is so arranged, however, that after about 30 seconds both contacts T1 and T3 open and de-energize the engagement and main relays respectively. The motor circuit is thus opened and the overspeed relay can then re-open. The system then re-sets itself as described in sub-para. (5) above.

(7) For relighting in flight, the appropriate relight push switch is depressed. This energizes the ignition relay, closing contacts 11 and so completing the circuits to the fuel valve solenoid and the high energy ignition units. Contacts 12 open and prevent operation of the bleed-off valve, which is not used under flight conditions.

Cartridge turbo-starters

14. Single, twin, or multiple breech types may be installed, the basic circuit being the same in each case, except that a cartridge selector switch is necessary for twin and multiple breech types. This switch comprises two rotary switch arms mechanically coupled to the starter push switch. One switch arm completes a circuit to a different cartridge each time the push button is depressed, while the other switch arm automatically earths the circuits to the remainder of the cartridges. A typical circuit, incorporating a twin-breech cartridge selector switch is shown in fig. 3 and described below.

15. The time delay switch used in this circuit is motor driven, its speed being governed by a centrifugal switch. A solenoid operated clutch connects the motor drive to the camshaft operating the contacts. At the commencement of a cycle, contacts A are open and the remainder are closed. The starting procedure is the same as described in the preceding paragraphs, and the sequence of operations is as follows:—

(1) On depressing the starter push switch, the cartridge selector switch rotates, one switch arm completing the firing circuit to No. 1 cartridge, and the other arm earthing No. 2 cartridge. Since contacts C are initially closed, No. 1 cartridge is immediately fired, and the turbo-starter runs the engine rotor up to speed. At the same time the ignition relay closes and completes the circuit to the fuel valve solenoid and the high energy ignition units.

(2) The time delay switch motor starts running and the clutch solenoid is energized via contacts B. The clutch engages and the time cycle commences. Contacts A close immediately and complete the circuit to the hold-in coil of the starter push switch.

(3) After five seconds, contacts C open and interrupt the cartridge firing supply.

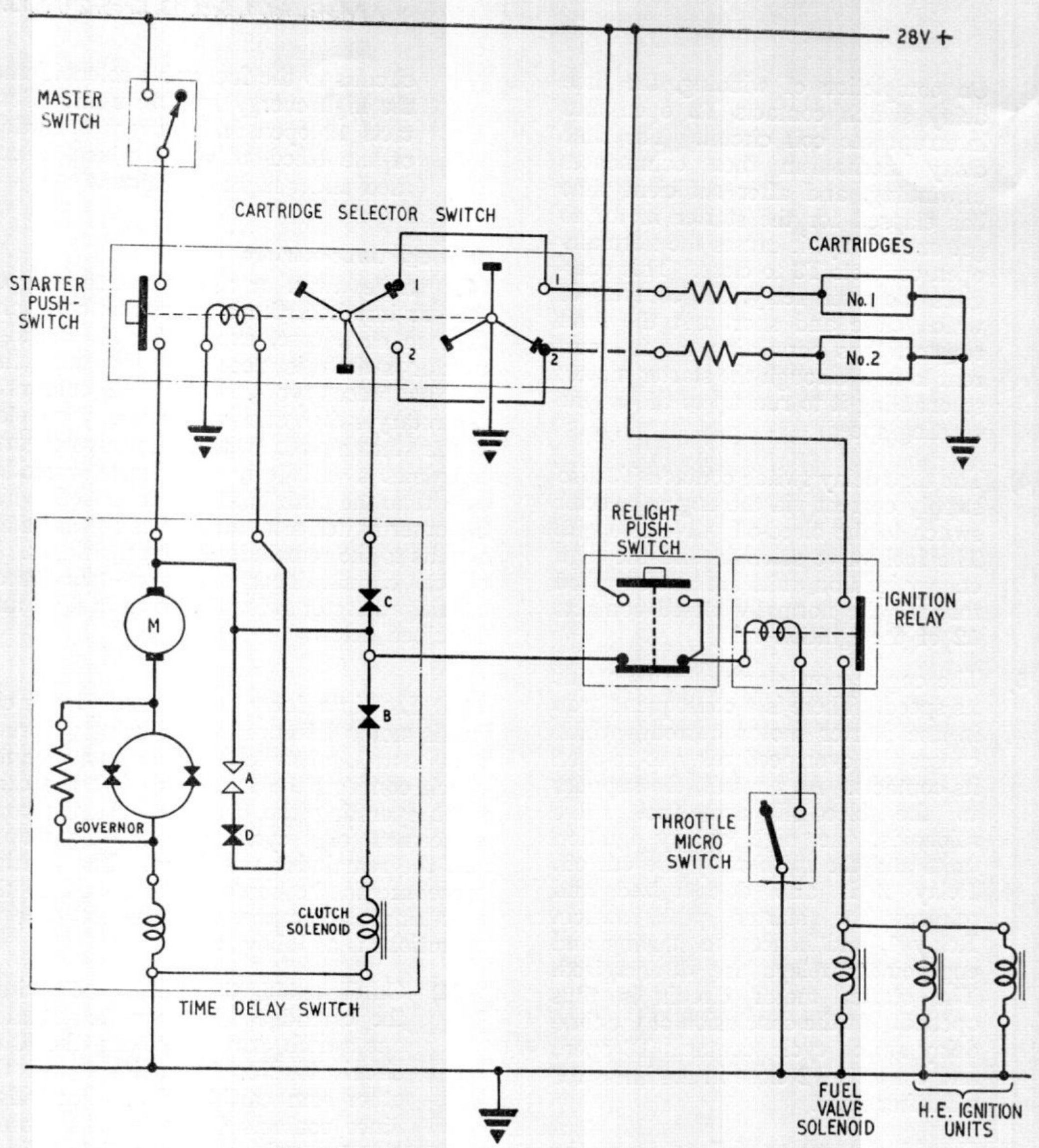

Fig. 3. Turbo-starter system

(4) After 28 seconds, contacts D open and break the circuit to the hold-in coils. The starter push switch is released and cuts off all supplies. The ignition relay re-opens and the fuel valve solenoid and ignition units are de-energized. The time delay switch clutch disengages and the switch re-sets itself by spring action in readiness for a further cycle.

(5) Contacts B function as an over-wind safety device when bench testing the equipment, or, in the event of the starter push button sticking in the closed position. Should the supply remain on for any reason after contacts D have opened, contacts B open after a further two seconds and allow the clutch to disengage the motor. The switch can then re-set and commence a second cycle. Overwinding is thus prevented

(6) Should the engine fail to start, the starter push button may again be depressed. No. 2 cartridge would then be selected and fired, the time-delay switch completing its cycle exactly as described in the foregoing sub-paragraphs.

Cartridge turbo-starter TSC 50

16. This is a multiple breech starter with a firing head which contains a selective firing pin for each cartridge. The firing pins are geared to a geneva wheel so that each pair of diametrically opposite pins is selected at a time. The geneva wheel is operated by an electric motor. Overspeed contacts, fitted to the turbine, are arranged to cause failure of the fuse in the motor circuit when the starter rotor exceeds the safe operating speed. The control unit used in this system determines the starting cycle of the aero-engine by timing the indexing and firing operations; also by energizing the aero-engine ignition system before the start, and by controlling the throttle by-pass valve.

17. A simplified circuit of the electrical system is in fig. 4; the sequence of operations is as follows:—

(1) When the starter push button is operated, current is connected from the aircraft electrical system to the time switch and the coil of the throttle by-pass relay RL.2. The time switch motor is started and, at the beginning of its cycle, closes switch C, which completes the circuit to the coil of the ignition relay RL.5. Contacts on this relay provide a supply from the electrical system to the aero-engine ignition system.

(2) After about two seconds, switch B is closed by the action of the time switch motor and completes a " hold-on " circuit for relay RL.5, and for the time switch motor, via the contacts of relay RL.5.

(3) Following a further two seconds (approximately) of the timing cycle, switch A is closed for about 0·065 seconds, energizing the indexing relay RL.3 through contacts on relay RL.2 and relay RL.4. A circuit is then completed, via the contacts of relay RL.3, to the indexing motor causing it to index and fire a cartridge. Additional contacts on relay RL.3 provide a " hold-on " circuit for the relay and an alternative circuit for the indexing motor via the motor switch.

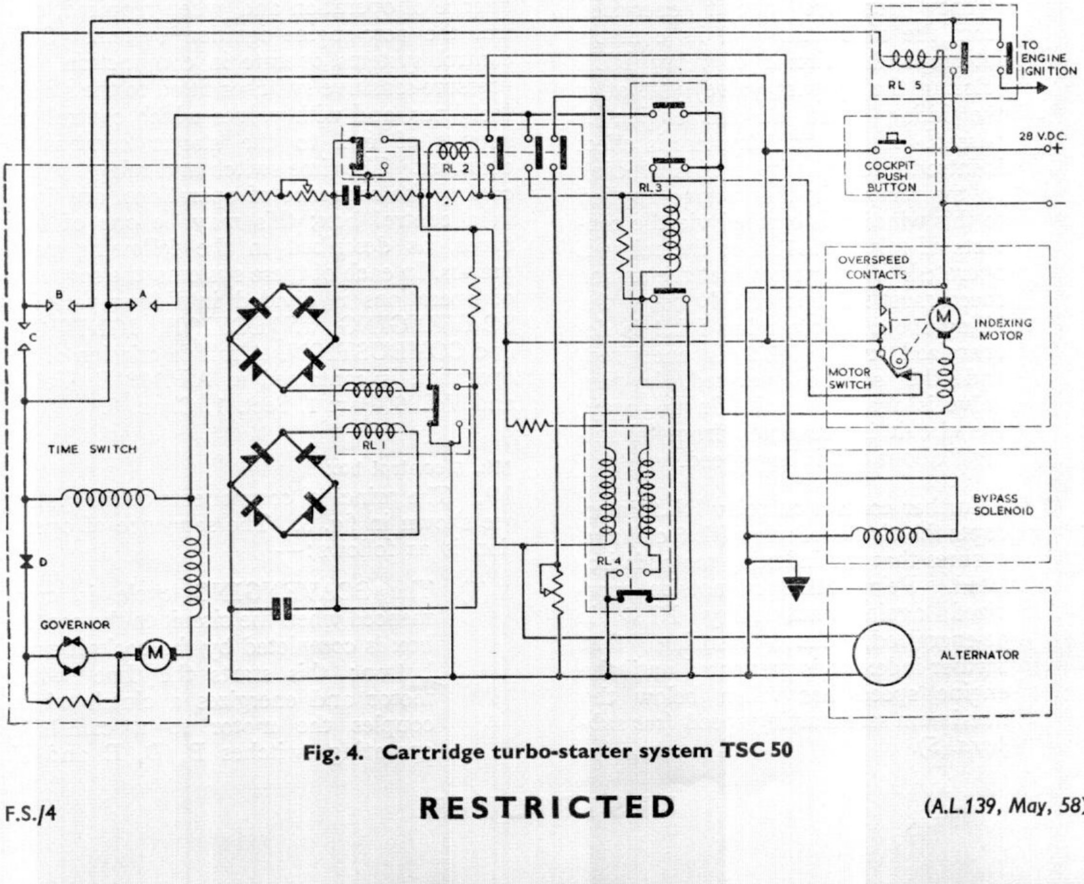

Fig. 4. Cartridge turbo-starter system TSC 50

(4) On the completion of the indexing cycle, and after contacts A have opened, the motor switch contacts open and interrupt the circuit to the contacts of relay RL.3. The indexing motor is then isolated and relay RL.3 is de-energized.

(5) When the starter reaches 400 r.p.m., relay RL.4 is operated by a voltage from the alternator via contacts on relay RL.2. The contacts of relay RL.4 interrupt the normal closing circuit of relay RL.3, which (if energized) is held on via its own contacts and, once de-energized, will not operate again during the present cycle (*see sub-para.* 9); the contacts of relay RL.4 also complete a bias circuit for the coil of RL.4 (*see sub-para.* 7). At 400 r.p.m. the engine ignites, and then accelerates to idling speed.

(6) Control of the engine during the idling period is provided by the throttle by-pass valve, operated by the by-pass solenoid (*fig.* 4). The circuit of the by-pass solenoid is completed (and the valve opened at starting) by contacts on relay RL.2, which in turn is controlled by contacts on relay RL.1. This relay is operated from a frequency sensitive circuit energized from the alternator, and its contacts interrupt the circuit of relay RL.2 (closing the by-pass valve) just after the idling speed of the engine is passed. An artificial hysteresis effect is introduced by using a bias winding on the relay coil; the voltage applied to this winding is earthed via the contacts of relay RL.1 after the relay is operated. This ensures that the engine speed must fall appreciably below the idling speed before relay RL.1 is de-energized, relay RL.2 is energized, and the solenoid-operated, by-pass valve is again opened. In this way, the circuit is prevented from "hunting" about the idling speed.

(7) A further contact on relay RL.2 interrupts the circuit of relay RL.3 coil and ensures that the indexing motor is isolated. Relay RL.3 cannot be energized again until relay RL.4 is de-energized, thus ensuring that further indexing is prevented until the engine speed has fallen below the maximum safe starting speed (*see sub-para.* 5).

(8) Approximately 18 seconds after the starting sequence is commenced the time switch motor opens switch B. This de-energizes the time switch motor, de-energizes the coil of the ignition relay RL.5 (thus switching off the engine ignition system) and interrupts the supply to the starter system.

(9) The system now returns to the start position, but cannot be operated again until the engine speed has fallen below the maximum safe starting speed. This safety factor is introduced by relay RL.1, which will remain energized above the safe speed owing to the voltage from the alternator; the contacts of this relay prevent relay coil RL.2 from being energized if the starter push button is pressed during the run-down period. Relay RL.4 is similarly energized and prevents operation of the indexing relay RL.3 (thus ensuring that the indexing motor remains stationary) until the speed is below the safe starting level.

Liquid fuel turbo-starters LTSA 150 and LTSA 70

18. Liquid fuel turbo-starters are fitted with control systems which govern the timed sequence of operation and, when required, control the aero-engine ignition system. Such control systems operate in conjunction with pressure-sensitive switches fitted to the starter fuel lines, and with valves which control the supply of fuel to the starter combustion chamber. The time switch and relays, which control the sequence of operations, are fitted in a control box; this may be one of four types, as described in the following paragraphs. In each of these systems, the sequence of operations is divided into four periods: SCAVENGING, INJECTION, IGNITION, and COMBUSTION. A full description of the operation is contained in A.P.1181B, Vol. 1 and Vol. 6, Part 1, Sect. 1, Chap. 3.

Mk. 5 control box

19. The principal components of the system are shown in fig. 5. The sequence of operation is as follows:—

(1) The SCAVENGING cycle is commenced when the circuit to the control box is completed by the cockpit push button: this starts the time switch motor and energizes a clutch which couples the motor to a camshaft, operating switches B, D, E and F.

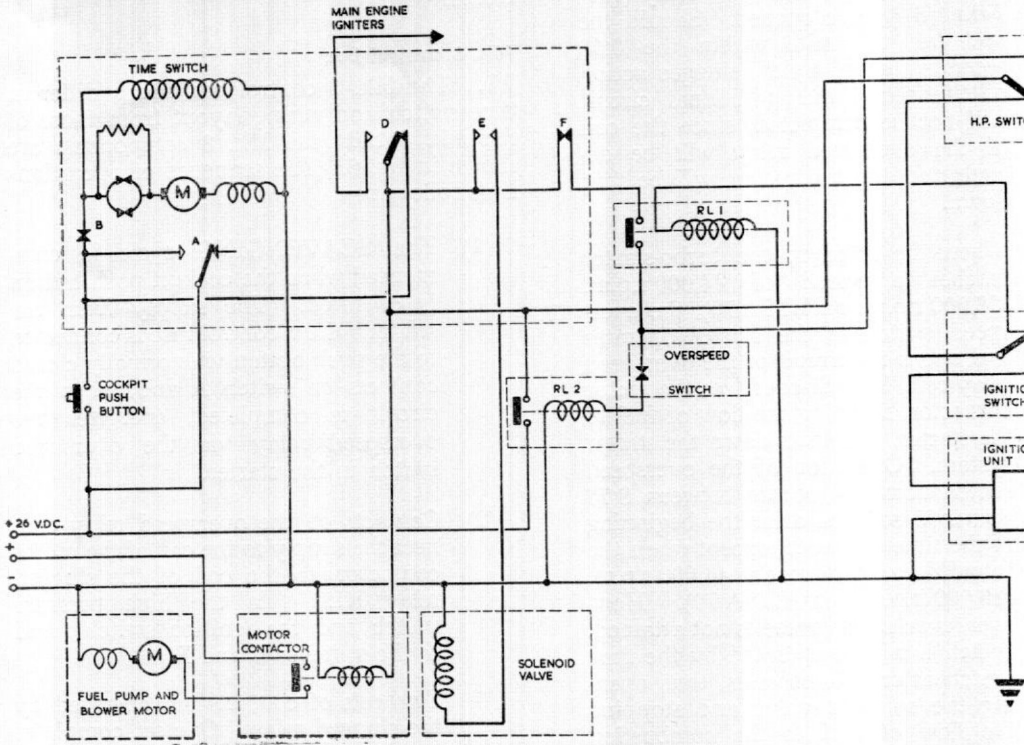

Fig. 5. Liquid fuel turbo-starter with Mk. 5 control system

The movement of the clutch also closes switch A, which by-passes the cockpit push button and ensures continuity of supply to the motor throughout the timing sequence.

(2) Also at the beginning of the timing cycle, the motor contactor is closed, via switch D, and starts the air blower and fuel pump motor. The slugged relay RL.1 (slugged on opening) is also energized, via switch D, the high pressure switch and the ignition switch; this completes a circuit to the coil of the overspeed relay RL.2 via switch D, switch F and the overspeed switch. An alternative supply circuit to the motor contactor and the coil of the slugged relay, when the cockpit push button is released, is provided by the contacts of the overspeed relay.

(3) After 1·75 seconds, switch D is operated by the camshaft and energizes the aero-engine igniters. In certain applications of the equipment, this switch is not used and the igniters are controlled from the aircraft system.

(4) The INJECTION cycle starts after 2·75 seconds, when switch E closes and energizes the solenoid valve in the fuel system. Fuel is then passed into the combustion chamber of the starter.

(5) The IGNITION cycle commences about 3 seconds from the beginning of the time cycle. The increasing pressure of fuel in the fuel line operates the ignition switch, which energizes the high frequency ignition unit and, at the same time, cuts off the supply to the coil of the slugged relay.

(6) The COMBUSTION period commences with the ignition of the fuel and the operation of the high pressure switch, which is actuated by the rise in pressure in the fuel line due to combustion. This stops the supply to the ignition unit and completes an additional circuit to the coil of the overspeed relay RL.2.

(7) This circuit to the overspeed relay (*sub-para.* (6)) is normally made before the contacts of the slugged relay (*sub-para.* (5)) have opened. Should the fuel fail to ignite within the 0·18 seconds allowed by the slugged action of the relay, this additional circuit will not be completed, since the coil of the overspeed relay will be de-energized and the system will be shut down.

(8) When the rotor in the turbo-starter reaches a speed of 44,000 r.p.m. (38,000 r.p.m. on LTSA 70), the overspeed switch in the starter operates and opens the circuit of the overspeed relay coil. This de-energizes the motor contactor, stopping the flow of fuel to the starter, and shuts down the starter system. Operation of the overspeed switch normally occurs between 8·75 and 9·75 seconds after the beginning of the time sequence, except when the rotor does not reach 44,000 r.p.m. (38,000 r.p.m. on LTSA 70). However, even if this speed is not attained, switch E will be operated by the time switch after 9·75 seconds, thus opening the solenoid valve and stopping the flow of fuel to the combustion chamber. This causes the high pressure switch to return to its normal position and shut down the system.

(9) After about 18 seconds, switch B in the control box is operated and its contacts interrupt the supply to the time switch motor. The time switch then automatically re-sets for the next start.

(10) Switch F provides a safety factor in the event of the slugged relay contacts sticking in the closed position. Should the slugged relay fail to close down the starter, sub-para. (7), the opening of switch F (1 second after contact E closes) stops the supply of fuel to the starter and shuts down the starter system.

Mk. 5 control box with Mod. 186 fitted

20. Modification 186 involves the fitting of a new time switch in the control box Mk. 5, thereby introducing a new timing sequence. The operation is basically that described in para. 19, but the timing of switches D and F is changed to conform with that of the Mk. 8 box. During the SCAVENGING cycle, switch D energizes the aero-engine ignition after 0·5 seconds, and, in the COMBUSTION cycle, switch F opens 0·45 seconds after switch E closes.

Mk. 8 control box

21. The Mk. 8 control box has a different time switch and wiring layout from those of the Mk. 5 box; the Mk. 8 components are shown in fig. 6. The sequence of operations is as follows:—

(1) The SCAVENGING cycle is commenced when the cockpit push button is operated. The supply from the starter system control fuse is connected to the push button via normally closed contacts on switch A and, when the circuit is completed, energizes the overspeed relay via the overspeed switch in the starter.

(2) Contacts on the overspeed relay connect the supply to the coil of the motor contactor, to the coil of the slugged relay RL.1 (via the high pressure switch and the ignition switch), and to the switches E and F.

(3) Two sets of contacts are operated by the slugged relay. One set completes an alternative circuit to the overspeed relay coil (via switch F and the overspeed switch), and the other set (which operate shortly afterwards) start the time switch motor. The first set hold in the overspeed relay when the cockpit push button is released.

(4) Immediately the time switch motor is energized, a clutch is actuated and connects the motor shaft to a camshaft which operates switches B, D, E, and F; the movement of the clutch also operates switch A, which disconnects the supply to the cockpit push button and completes an alternative circuit to the time switch motor. The aero-engine ignition system is energized at the same time as the time switch motor, the supply being taken from the slugged relay contacts.

(5) Switch D provides a safety factor in that if the high pressure switch operates for any reason immediately on starting the system fuse will fail. This factor is removed, in preparation for the normal operation of the high pressure switch, when switch D is operated after 0·5 seconds.

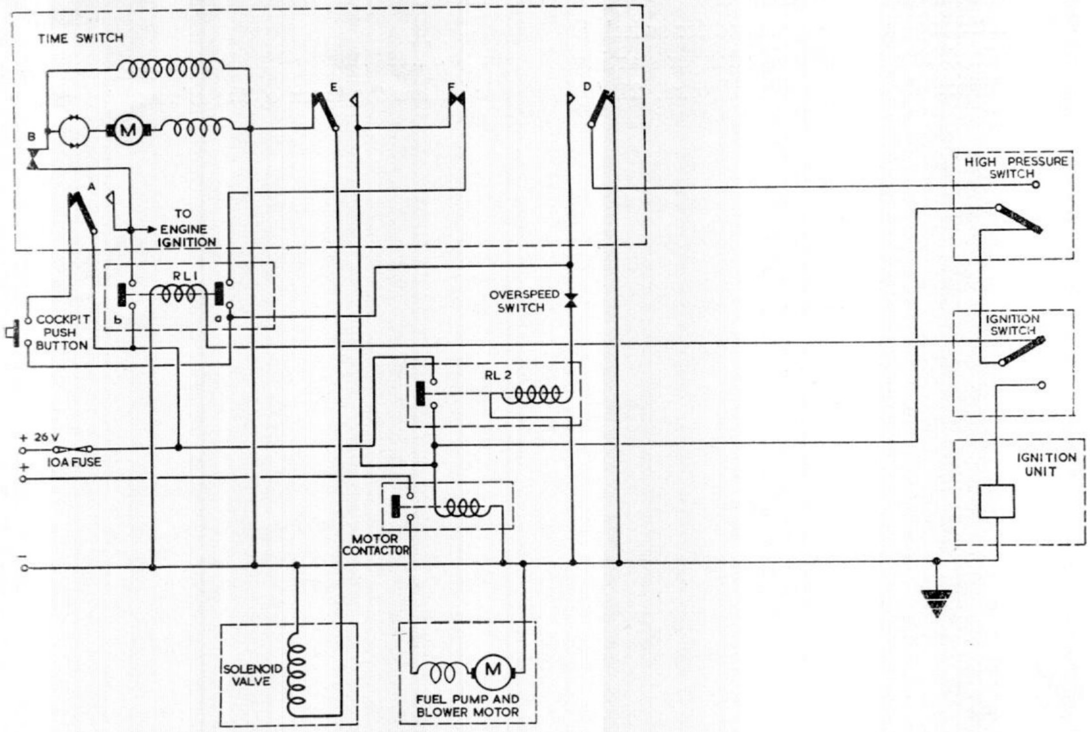

Fig. 6. Liquid fuel turbo-starter with Mk. 8 control system

(6) The INJECTION cycle is commenced after 2·75 seconds, when switch E is operated and the solenoid valve is energized; this closes the fuel by-pass line to the supply tank and causes the fuel to flow into the combustion chamber.

(7) The IGNITION cycle commences with the operation of the ignition switch, which de-energizes the coil of the slugged relay RL.1, and energizes the starter ignition unit. Owing to the slugged operation of this relay the contacts do not open for 0·18 seconds, by which time combustion is normally accomplished.

(8) The COMBUSTION cycle starts when the high pressure switch is operated, and normally continues until the starter rotor reaches a speed quoted in the Leading Particulars, when the overspeed relay operates. This closes down the starter by de-energizing the coil of the overspeed relay RL.2, de-energizing the fuel pump and air blower motor contactor and stopping the supply of fuel to the starter. In the event of the fuel not being ignited, the overspeed relay is de-energized by the action of the slugged relay contacts, which open after 0·18 seconds (*sub-para.* (7)).

(9) The time taken for the starter rotor to reach 44,000 r.p.m. (38,000 r.p.m. on LTSA 70) is normally between 8·75 and 9·75 seconds. Should the start take longer than this time, the system will be shut down by switch E, which re-opens 9·75 seconds from the commencement of the timing cycle.

(10) Finally, switch B is opened by the camshaft after 18 seconds and de-energizes the timing motor. The camshaft then returns to the start position.

(11) In the event of the starter failing to ignite, and the contacts of the slugged relay sticking, switch F opens the circuit to the coil of the overspeed relay and shuts down the starter system. This is timed to occur 0·45 seconds after switch E closes.

Mk. 9 control box

22. The circuit of the Mk. 9 control box is identical with that of the Mk. 8 box (*fig.* 6). A different timing cam is introduced for switch E in the Mk. 9 box and allows a longer starting period before the shut down of para. 21 (9) is applied. The operation of switch E occurs 12·75 seconds after the timing period has commenced.

Note . . .

The times quoted in the preceding paragraphs are the mean of the allowed tolerances.

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